Machinery Messages

Case History

Using ADRE® 3 to on a pressurized wat

Portability plus powerful software make ADRE® 3 the ideal system for diagnosing problems on rotating machinery.

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Since the introduction of ADRE® 3, Bently Nevada has seen this uniquely flexible instrument used in many different applications to document machine condition and diagnose the causes of problems. This case history focuses on the use of ADRE 3's data acquisition and display capabilities by the technical trouble-shooting staff of an original equipment manufacturer. What is unique about this application is that the ADRE 3 was taken along on a trouble-shooting trip from the USA to Europe and back. ADRE 3's portability and rugged construction makes it an ideal companion on such a trip.

This case documents a problem on a reactor coolant pump (RCP) in service at a Pressurized Water Reactor (PWR) nuclear power plant in Europe. The pump had experienced vibration problems and plant personnel contacted Westinghouse for help. Stan Jenkins, a Senior Design Engineer of Westinghouse's EMD Division, is one member of a highly capable staff who trouble-shoots RCP problems when they occur. Stan routinely uses the ADRE 3 system to obtain and review vibration data.

The reactor coolant pump is a vertically oriented machine which circulates primary coolant from the pressurized water nuclear reactor through a steam generator. It is a centrifugal pump driven by a 1480 rpm, 7000 HP motor. The pump circulates approximately 94,000 gallons per minute (gpm) of coolant at 550°F (288°C) and 300 ft. (100 m) of head. The motor and pump are rigidly coupled since the entire machine has only three radial bearings (two oil lubricated, pivoted-pad motor bearings and a large water-lubricated plain journal bearing, L/D = 1). The pump bearing is maintained at a low temperature, relative to the pumped fluid, by the injection of cool water into the seal/bearing area and by the thermal barrier heat exchanger just below the bearing assembly. Coolant enters the machine from the bottom of the casing and exits through a tangential discharge. The hydraulics are designed to provide a 2000-3000 lb (907 to 1361 kg) radial side load (depending upon water temperature) on the impeller to provide a static load on the radial bearings. Figure 1 illustrates the machine arrangement.

Vibration monitoring instrumentation on this pump is typical of most Westinghouse Reactor Coolant Pumps. Monitors in the control room of the plant receive inputs from two proximity

diagnose problems
er reactor coolant pump

probes installed on the pump coupling, a Keyphasor® probe and two Velocity Seismoprobes®. The vibration probes and the Keyphasor transducer are mounted on the top of the seal housing viewing the coupling. The Velocity Seismoprobes are mounted on the bottom of the motor frame. The coupling probe and Velocity Seismoprobe pairs are in the standard XY arrangement to provide complete information on shaft and frame motion in the plane of the probes. Refer to Figure 1 to note that the coupling proximity probes are about halfway between the pump water bearing and the lower motor radial bearing.

The ADRE®3 (108 DAI) Data Acquisition Instrument can record up to eight channels of vibration signals synchronized to one Keyphasor signal. When using it for a typical RCP, Stan Jenkins uses only one half (4 channels) of its capacity.

Stan was first introduced to this problem when the plant operators requested Westinghouse's assistance in June, 1988. Vibration levels on the control room monitors showed overall vibration magnitudes on one of the power plant's three pumps were cycling over a 6 mil (150 μm) range and exceeding the "Alert" level of 10 mils (254 μm) peak to peak. The period of the cycle was 1-2 minutes. Stan set up the ADRE 3 to►

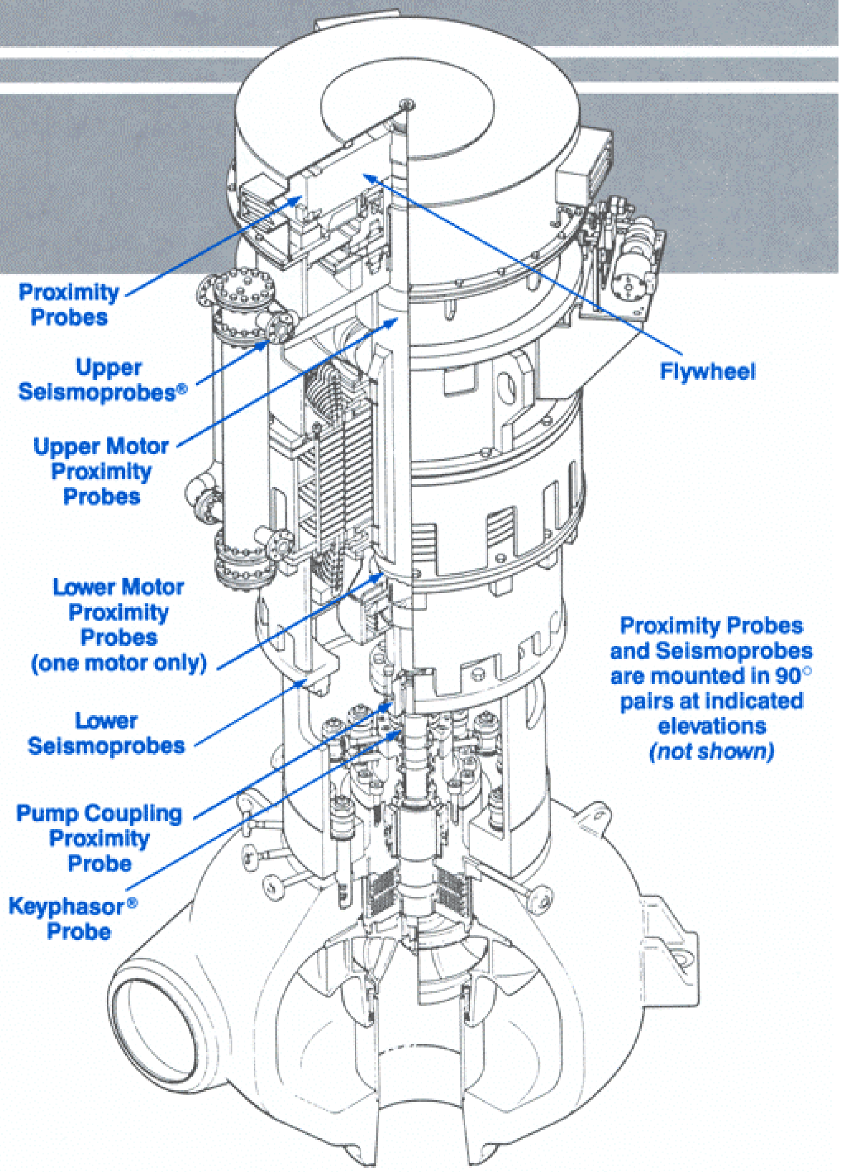

Figure 1
Diagram of a reactor coolant pump

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obtain data. In addition to vibration data, Stan documented the following related information which assisted him in determining the cause of the high vibration levels.

- The problem initiated unexpectedly during normal, 100% power plant operation in late April, 1988.
- The leak off flow from the No. 1 seal (located just above the pump bearing) cycled with the same period as the vibration cycling period.
- The magnitude of vibration and the cycling period were insensitive to changes in the cooling water flow rate and temperature into the thermal barrier (located between the pump impeller and the pump bearing), as well as to changes in flow and temperature of the seal injection water.
- Initially, the high vibration levels were not present. The onset and disappearance of the high vibration levels had been random. However, upon each subsequent occurrence, the high vibration appeared to continue for a longer period of time.

Initial data acquisition and review

With the 108 DAI, Stan obtained steady state data at plant full power conditions. Using ADRE®3 Software, he plotted Bodé, Shaft Centerline and Spectrum plots. From data obtained via the proximity probes, the (APHT) Amplitude & Phase versus Time plots generated (Figure 2) revealed vibration cycling with relatively minor changes in phase angle. The Spectrum plots (Waterfall format, Figure 6) also illustrated the vibration cycling, the presence of submultiple components and multiple components above running speed, but only at certain times during each cycle's period.

Other plots were more revealing. At steady state conditions, the Shaft Centerline plot (Figure 7) indicated that the shaft was moving radially within the bearing clearance. More importantly, it indicated the variation occurred in a clockwise precession, opposite to the rotational direction of the pump shaft. Seismic transducers mounted on the motor frame revealed little additional information on the nature of the problem.

After seeing the reverse precession direction of the shaft centerline, Stan suspected a rub condition. The unusual pattern of submultiples had hinted that rubbing was a possibility. However, lack of Keyphasor signal jitter and the slow changes in the vibration levels did not fit the traditional ideas of what a rub usually looks like (though they didn't contradict the notion that a rub could still be present). Stan likened this motion to a "lubricated dry rub". A full dry rub produces backwards precession at much higher speed (and usually quickly destroys the machine). This motion is primarily forward spin of the rotor with a small component of torsional drag due to rubbing causing the rotor to precess backwards slowly.

Consideration of other possible mechanisms which would generate such motion was limited to on-site discussions with operators and engineers about motor electrical phase balance. There were no obvious unbalances as prior recent maintenance checks had revealed no abnormalities. The rub hypothesis remained as the primary explanation for the problem. The ADRE 3 data supported this hypothesis.

First attempted problem correction

Immediate resolution of the problem was not possible as all the RCPs needed to be operating to maintain this condition. The plant had been at 100% power during the period of data acquisition. In view of this, Stan recommended checking the lower motor bearing area for rubs on the labyrinth seal at the next forced or refueling outage. The pump could continue to operate in its present condition, since levels were less than the shutdown limit, and the condition was very stable and repeatable. Since elimination of rubber "splash guards" in the seal package in 1972, the only radial rub problems of any duration on other machines had been in this area. Cycling vibration and oscillating seal flow, however, had never been associated with the problem.

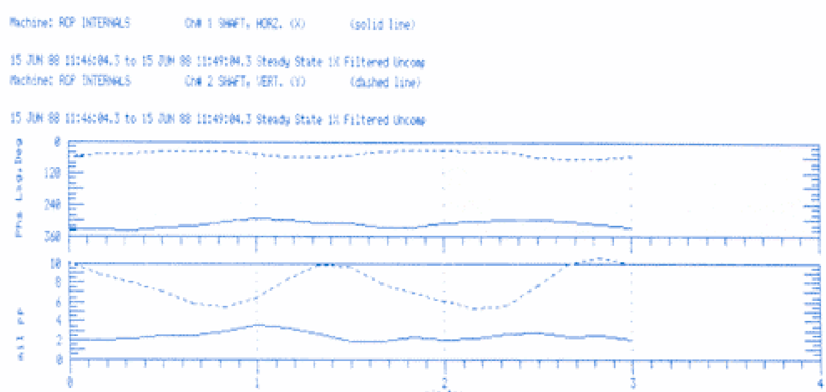

Figure 2

To explain how all of the other observations were consistent with the vibration data (something that is very typical of nuclear power plants), Stan also provided a detailed assessment of the relationships between the cycling vibration, the slow precession of the shaft and the seal oscillations using the ADRE 3 data as the basis. (See "How the RCPs Problems Related to each other" for details.)

When the plant was taken off-line for a short outage in July, 1988, the lower motor bearing and labyrinth were inspected. Though not directly viewable without time-consuming disassembly, the labyrinth in question did not appear to be rubbed and the labyrinth center appeared to be good relative to the bearing center. One bearing shoe out of seven was found to be gapped at 16 mils (400 μm) rather then the required 6 to 8 mils (150 to 200 μm), but this did not seem to be enough to fully explain how the labyrinth could be rubbed and produce the problems just documented. Motor and pump bearing alignment was checked and found to be within specification after the one shoe was reset.

Second data acquisition survey and review

When the pumps were restarted to heat up the plant, the cycling vibration problem returned almost immediately. However, there were some short periods of normal operation (no cycling) as had been the case when the problem first started. Stan was never present at the plant when these normal periods occurred. Standard brush recordings taken from the recorder outputs of the Bently Nevada monitoring system provided the documentation of this phenomenon. At the request of the utility, Stan brought the ADRE 3 equipment to the plant again to take more data. Now, startup/shutdown cycles of the pump could be studied to obtain a better definition of the problem.

This time it was possible to conclusively rule out the possibility of electrically-induced motion of the shaft centerline. Review of the shaft centerline plots taken when the pump was de-energized showed no significant sudden changes in shaft centerline which would indicate that the electrical field's center was considerably different from the rotor's mechanical center. Vibration surveys of the motor frame did not indicate anything unusual, eliminating the likelihood that any other mechanical problems existed in the unmonitored upper portion of the motor.

New information obtained affirmed the rub hypothesis and confirmed the explanations which related the oscillating seal flows and cycling vibration to the oscillations in shaft centerline position. Figures 9, 10, 11 and 12 show two coastdowns taken by the ADRE®3 equipment in the normal course of data acquisition which appear to have come from two very different machines. Correlation of these plots with the shaft centerline plots (not shown) proved that these two coastdowns were initiated when the shaft centerline positions were almost as far apart as they could be. Vibration amplitudes were also near the extremes of their ranges. Given this data, it was more certain that the variation in dynamic bearing constants was responsible for the oscillation in the amplitude of vibration.

Considering the magnitude of the reverse precession Orbit and the size of the radial clearances in the pump and motor internals, Stan decided there was only one plausible failure mode which was consistent with the rub hypothesis, a rub between the pump shaft journal and the bearing bore. The only problem with such an explanation was that this had never happened before. No one was too sure how the cartridge could have become stuck. The seat has a 3 to 8 mil (76 to 200 μm) clearance on its diameter. One of the most compelling reasons to accept this explanation as the source of the rub (no one doubted the rub existed) was that all other possible explanations were unsupported by the data available on this pump.

However, the need to produce power eliminated any chance to power the machine down and inspect the pump bearing. Since the levels were stable, it was decided to operate the plant until the next forced outage or refueling (May, 1989) was planned.

Third data acquisition survey and review

As the date for refueling approached, the pump developed other, apparently unrelated, problems which raised the level of concern for the pump in general.►

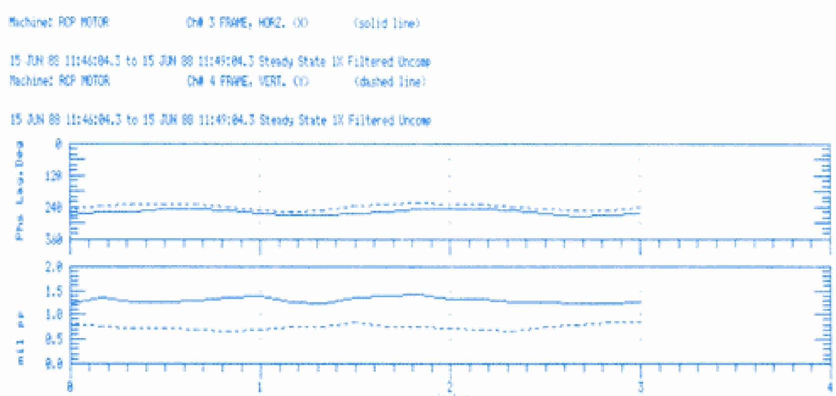

Figure 3

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Also, the vibration levels had started to trend upwards slightly and were occasionally crowding the shutdown limits. They never actually reached the shutdown values. To address these new problems and to determine if anything had changed between August, 1988 and April, 1989, Stan again took the ADRE® 3 system to Europe.

Vibration levels were cycling over a slightly larger range than before; the period of the shaft centerline backwards precession had dropped slightly. The submultiples (and harmonics of these frequencies) had dropped into the background on the linear spectra and Waterfall plots. The unfiltered shaft Orbits, with the increased amplitude of vibration, developed into a more classic impact-rebound type of Orbit (Figures 13 & 14). The filtered Orbits were highly elliptical, as they had always been, (Figure 15 & 16) indicating a highly restricted motion in one direction. A Waterfall plot (Figure 17) displayed a 2X component which varied in amplitude with the 1X component. Recent cracked shafts in RCPs in other plants (non-Westinghouse) had concerned the utility, but since this 2X component was steady and only a little higher than the data from the last evaluation, there was no reason for further investigation into the possibility of a cracked shaft.

Note: The ADRE 3's ability to store acquired data for later retrieval and diagnostic reevaluation in cases like this was critical to focusing the problem/solution. It is common to suspect every possible problem occurring in a machine when the problem source hasn't been found. Stan found the availability of an historical, easily transportable, diagnostic database of his prior work invaluable.

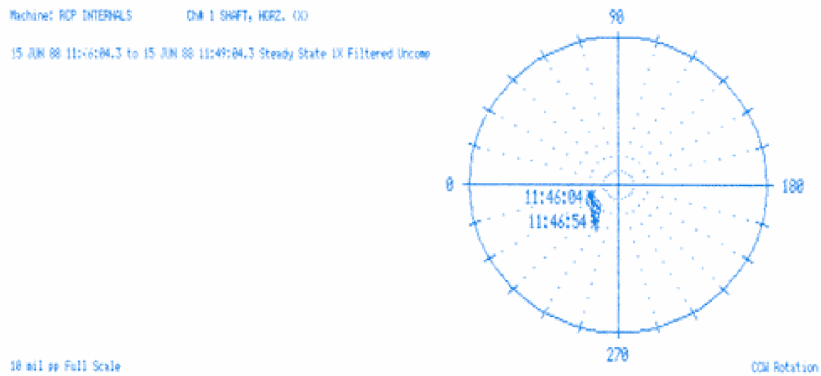

Figure 4

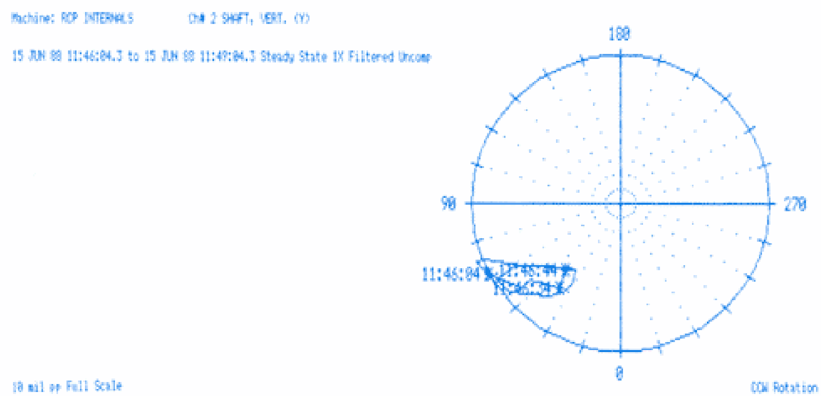

Figure 5

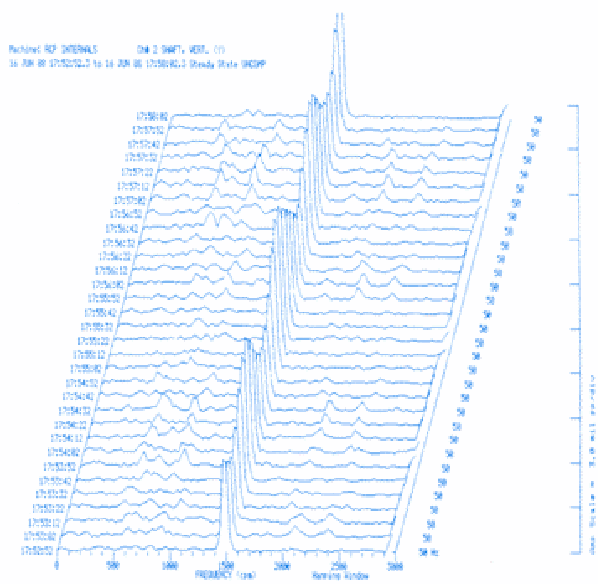

Figure 6

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Although some individuals still feared the possibility of a cracked shaft, further data strengthened this rub hypothesis and plant operation continued up to the scheduled refueling outage. The pump exhibited one brief period of normalcy between April and May, returning to its usual rubbing mode before shutdown.

The pump bearing was now available for inspection. It was extremely difficult to extract the bearing/housing assembly from the thermal barrier housing. Creative techniques (liquid nitrogen and removal of portions of the bearing/housing assembly) were eventually required to remove the parts. The logical conclusion was that the thermal barrier housing had shrunk, grabbed the bearing housing and closed up the 3 to 8 mil (76 to 200 μm) clearance of the bearing cartridge/split housing. The bearing was unable to pivot freely and was heavily rubbed on its edges, as had been predicted. The easiest repair method was to replace the pump internals with a spare and to salvage useable parts at a later date.

Restart of the plant with the replacement RCP was trouble free. Only conventional balancing was required to adjust vibration levels to desired levels.

The reactor coolant pumps were continuously monitored with proximity probes and motor frame mounted transducers. The monitors continuously displayed vibration levels in the plant control room. Display of vibration levels by these monitors allowed the plant to operate the RCP while a problem existed that was not of sufficient severity to require its removal from service. Without the monitors, the state or condition of this RCP and the extent of its problem, would not have been known. The vibration instrumentation and judicious utilization of diagnostic instrumentation allowed intelligent decisions to be made which permitted the continued operation of this pump.

The advantage of XY proximity probe transducers is clearly evident from this experience. Changes in sub-►

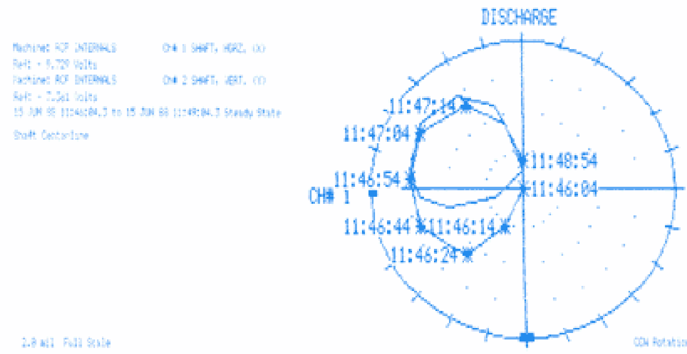

Figure 7

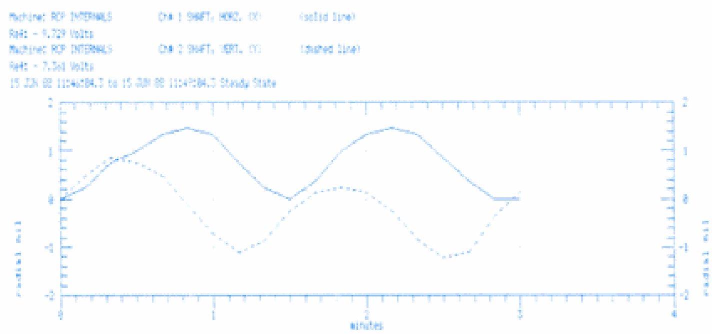

Figure 8

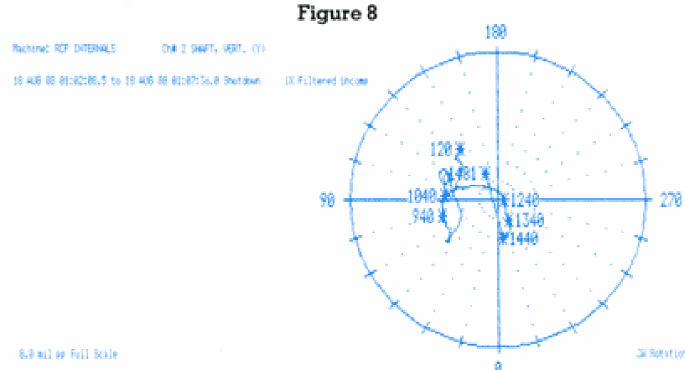

Figure 9

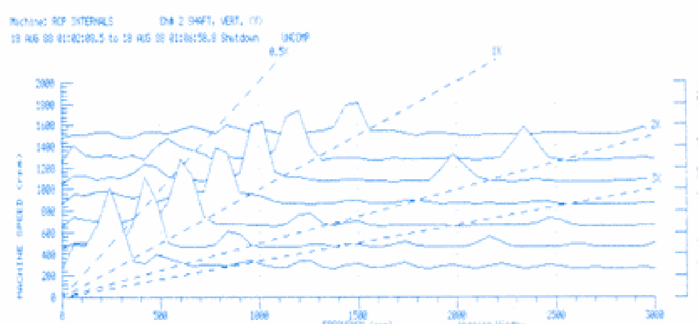

Figure 10

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... ADRE® 3, "I wouldn't go anywhere without it."

synchronous, as well as 2X and 3X frequency components, typically indicate that a problem exists. Their occurrence, however, generally does not pinpoint the cause of the problem. In this case, the availability of Shaft Centerline plots (obtained via probe gap data on the XY probes) immediately indicated that the shaft was moving radially in the bearing journals at steady state conditions. Orbit plots obtained from the proximity probes confirmed that the shaft had impacted something, further confirming the rub hypothesis. Clearly, a properly instrumented machine provides accurate information about a machine's condition. It eliminates a majority of uncertainties when attempting to diagnose a problem. If XY proximity probes had been used on the motor bearings, data from these transducers would very likely have indicated that the rub was not occurring in or near the motor bearings and the cause of this pump problem may well have been diagnosed earlier.

How the RCP's problems related to each other

The ADRE® 3 System alone cannot solve these kinds of problems. However, data acquisition techniques, coupled with the traditional, user-modifiable graphical/numerical displays of the data, give the vibration diagnostician tremendous flexibility and a database with potential use well beyond the immediate needs. Stan commented that he used to spend most of his time obtaining a few pieces of data; now he has all the data he needs. He only has to take time to determine which presentation of the data best describes the problem. Stan had the following comment regarding ADRE® 3, "I wouldn't go anywhere without it."

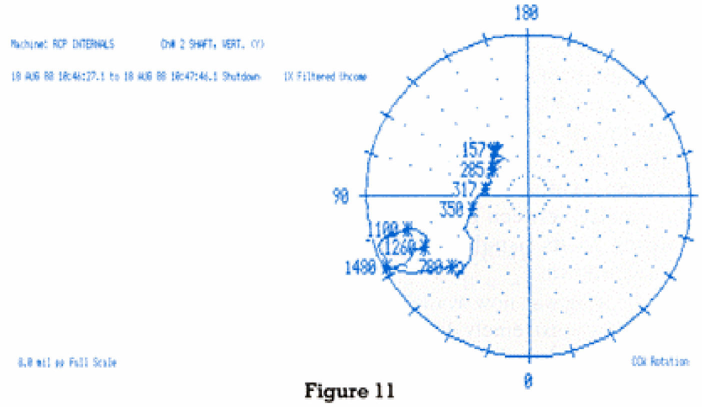

Figure 11

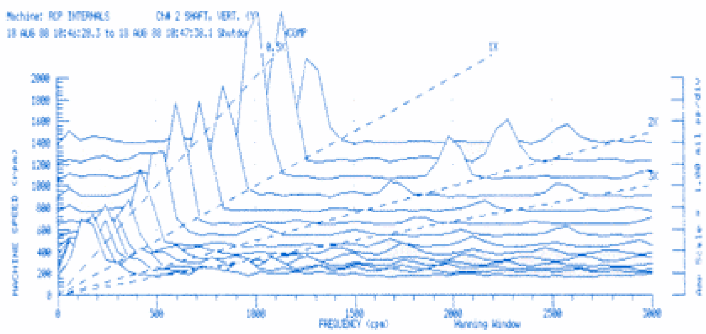

Figure 12

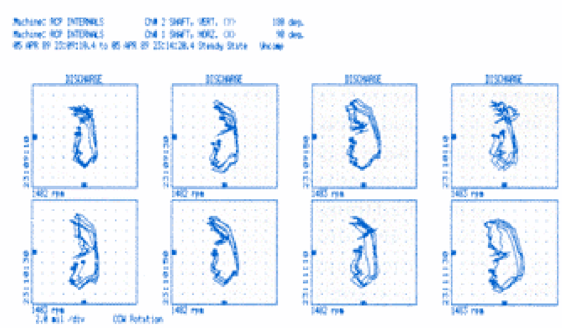
Figure 13

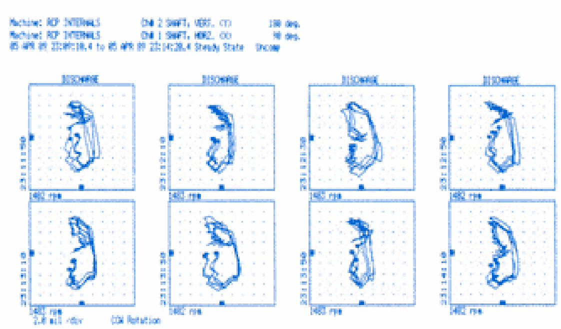
Figure 14

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The cycling vibration and backwards shaft precession are related to each other through the bearing dynamic spring/damping constants. All Westinghouse RCPs use hydrodynamic bearings. Thus, bearing constants depend heavily on rotor eccentricity within the bearing. As the shaft wanders about 2 mils (50 μm) at the pump coupling, it must also wander in all of the other bearings by some unknown amount. In the presence of a fixed unbalance load on the rotor, the rotor responds to the resultant change in bearing constants by sympathetic changes in running speed frequency vibration amplitude. This is exactly what the data shows.

Seal leak off oscillations follow due to the nature of the hydrostatic (film-riding) No. 1 Seal. It responds, by changes in the leak rate, to changes in relative seal ring/seal runner centerline position. The runner (just at the top of the pump bearing) is attached to the shaft and the seal ring is fixed radially and torsionally (floating axially) relative to the stationary seal housing. Seal leak off flows, and therefore oscillates, as a function of shaft centerline precession. Because the shaft precession is so slow, the seal leak off flow metering can follow this transient. The running speed frequency oscillations of the shaft occur too rapidly for the leak off flow metering to register a response (hence the lack of influence of shaft vibration on indicated seal leak off with this seal design).

More than one conclusion can be obtained from this experience. The ADRE® 3 is a multi-channel, portable diagnostic tool that can display steady state and transient data in the format the user desires. Data can be viewed immediately after its acquisition. Also, data can be stored and retrieved again for comparison with recently acquired data. Being portable, it easily lends itself to trouble-shooting machine problems in the field.

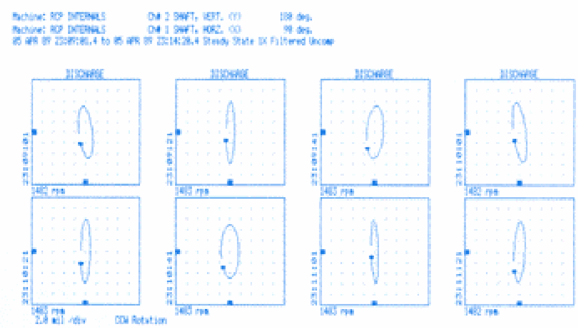

Figure 15

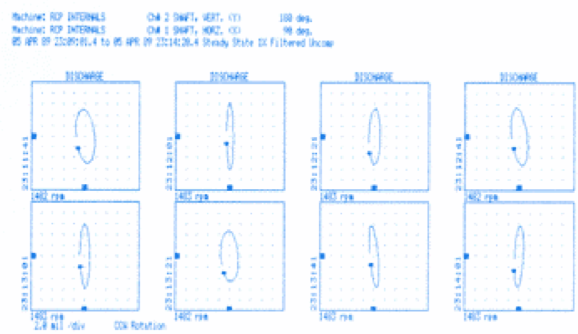

Figure 16

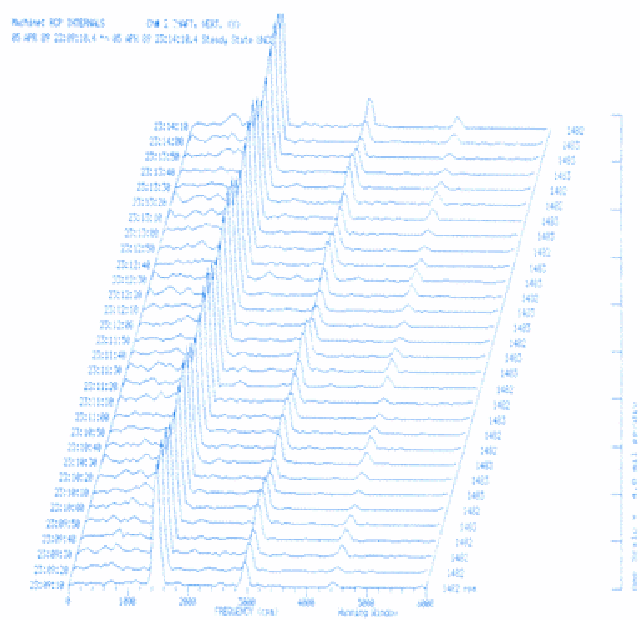

Figure 17

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